however, charged conductors take on a variety of shapes, but the same basic concepts about fields that apply to point charges also apply to conductors of all shapes. In fact, you can think of a conductor as a very large number of point charges lined up very close together. One important concept to remember when working with conductors is that electric field lines enter and leave a conductor perpendicular to the surface. Figure 8.2 shows why field lines cannot contact a conductor at any angle other than 90˚.

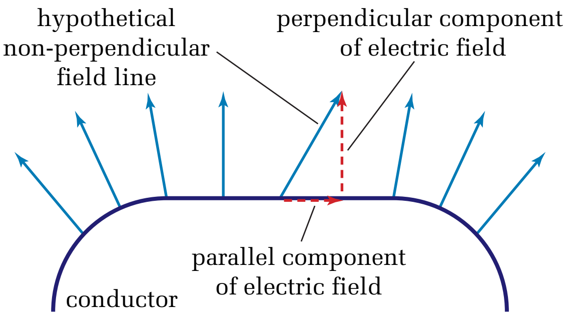
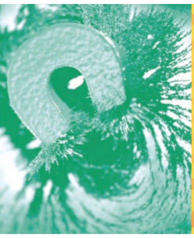


Figure 8.2 To indicate that an electric field line leaves a conductor at an angle implies that there is a component of the electric field that is parallel to the surface of the conductor. If this was the case, charges in the conductor would move until they had redistributed themselves in the conductor in a way that would change the field until there was no longer a parallel component.



QUICK LAB

Charge Arrays

TARGET SKILLS

- **Predicting**
- **Analyzing and interpreting**

In this Quick Lab, you will extend your knowledge into new and more complex charge arrangements. You will predict electric field lines and equipotential lines for several charge arrangements and then check your predictions.

For each of the following charge arrangements (arrays) located on the Cartesian coordinate plane, predict and sketch electric field line patterns and some equipotential lines. Use different colours for the field lines and for the equipotential lines.

(a) +1.0 C at (0,0)

(b) +1.0 C at (0,0) and an identical +1.0 C at (4,0)

(c) +1.0 C at (0,0) and –1.0 C at (4,0)

(d) +2.0 C at (0,0) and –1.0 C at (4,0)

(e) +3.0 C at (0,0) and –1.0 C at (4,0)

(f) +1.0 C at (0,0), +1.0 C at (4,0), and +1.0 C at (2,–4)

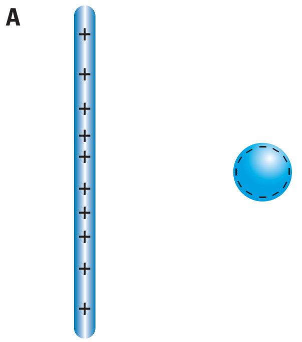
(g) +1.0 C at (0,0), +1.0 C at (4,0), and –1.0 C at (2,–4)

(h) +1.0 C at (0,0), +1.0 C at (4,0), –1.0 C at (4,–4), and +1.0 C at (0,–4)

Visit one of the Internet sites suggested by the Web Link on the previous page and simulate the charge arrays listed above. Observe the actual electric field lines and equipotentials that would be generated.

Analyze and Conclude

1. How well did your predicted patterns correspond to those generated by the simulation program?
2. How could you actually verify one specific value of the electric field intensity?



Consider the charged conductors in Figure 8.3 (A). Before you start to draw electric field lines, count the number of unit charges. Notice that the sphere has more negative charges than the plate has positive charges. So, more field lines will be ending on the sphere than leaving the plate. When you start to draw field lines, decide on the number entering and leaving each conductor so that the number of lines is proportional to the amount of charge on the conductor. Then, draw the beginning and end of each line perpendicular to the surface of the conductors, as shown in Figure 8.3 (B). Next, smoothly connect the lines so that those leaving the positive plate enter at adjacent lines ending on the negative sphere. The remaining lines on the sphere will spread out, but will not contact the positive plate. Finally, you can draw equipotential lines that are perpendicular to the electric field lines, as shown in Figure 8.3 (D).

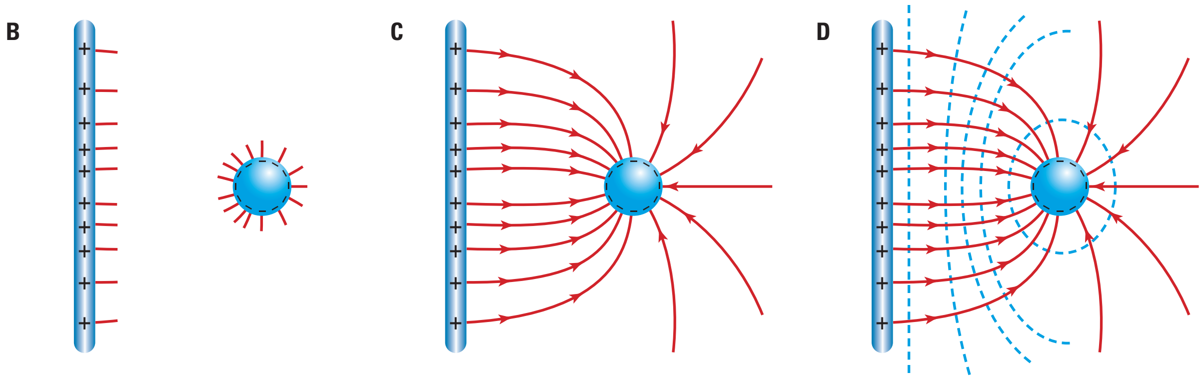
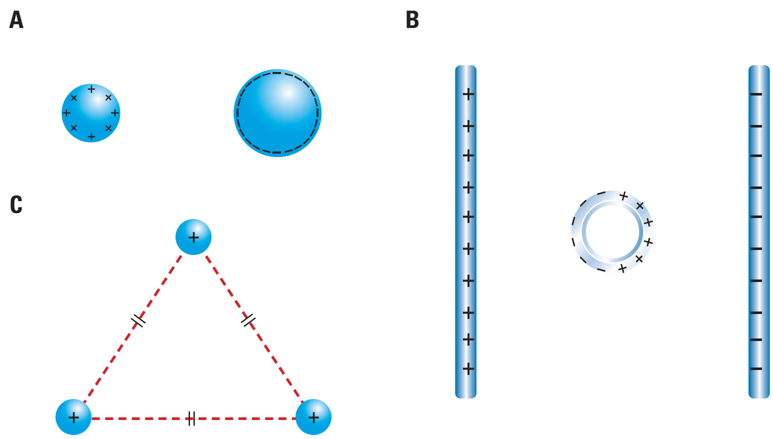


Figure 8.3 The positive plate attracts the negative charge on the sphere so that it is more dense on the side near the plate and less dense on the side away from the plate.

Conceptual Problem

- Copy each of the following diagrams (do not write on the diagrams in your textbook), showing various-shaped conductors, and draw in a representative sample of electric field lines and equipotential lines. Note that a uniform charge distribution has been assumed for each object except the cylinder in (B).



Parallel Plates

Charged parallel plates are a convenient way to create an electric field and therefore warrant in-depth examination. When two large, oppositely charged parallel plates are placed close together, the electric field between them is uniform, except for a certain spreading or "fringing" of the field at the edges of the plates, as shown in Figure 8.4.

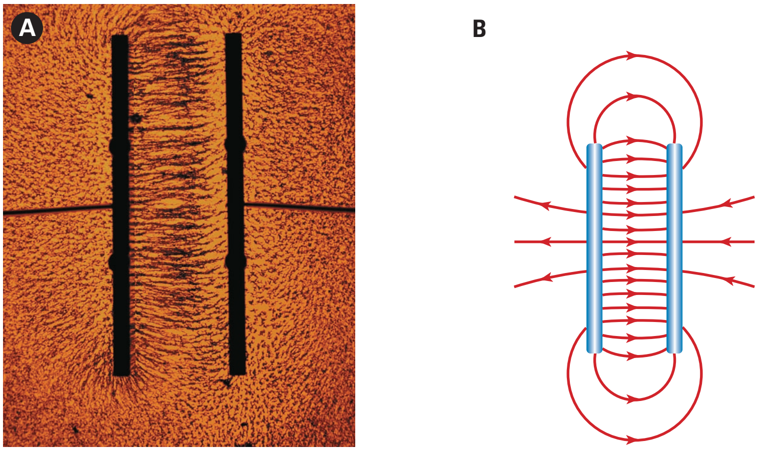


Figure 8.4 **(A)** When grass seeds are placed in an electric field between two parallel plates, they line up to reveal the shape of the electric field. **(B)** Using part (A) of this illustration as a model, a schematic diagram of an electric field is drawn.

The plates are too large to act like point charges, but the fact that the total charge on each plate is the sum of a large number of individual charges provides a way to explain the uniform field between the plates, as illustrated in Figure 8.5.

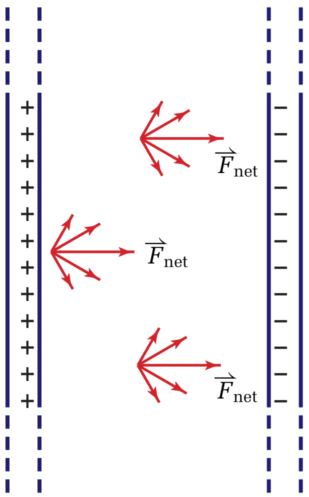


Figure 8.5 By symmetry, all of the force vectors add to produce a net force directly to the right.

A positive test charge placed at any point between the plates would experience a force from every positive charge on the left plate and every negative charge on the right plate. The magnitude of each of these forces would be determined by Coulomb's law, and the direction of each force would be along the line joining the test charge to each charge on the plates.

ELECTRONIC LEARNING PARTNER

To enhance your understanding of charges and fields, go to your Electronic Learning Partner.

PHYSICS FILE

It is important to remember that the parallel plates are mounted on insulators, isolated from any circuit. If they were charged by a battery, the battery was disconnected, so the same amount of charge would remain on the plates. If instead the plates remained connected to the battery and, for example, the area of the plates or the distance between them was changed, the battery would then adjust the charge on the plates and the field would change as well. Parallel plates connected within a circuit are called "capacitors" and their operation is beyond the scope of this course.

The net (resultant) force on the test charge would then be determined by the vector sum of all of the forces acting on it. Since the system is perfectly symmetrical, for every upward force, there would be a force of equal magnitude pointing down. The net force on the test charge would be a constant vector perpendicular to the plates, regardless of its location between the plates. The resulting field between two parallel plates can be summarized as follows.

- The electric field intensity is uniform at all points between the parallel plates, independent of position.
- The magnitude of the electric field intensity at any point between the plates is proportional to the **charge density** on the plates or, mathematically, $|E_Q| \propto \sigma$, where $\sigma = q/A$ (charge density = charge per unit area).
- The electric field intensity in the region outside the plates is very low (close to zero), except for the fringe effects at the edges of the plates.

SAMPLE PROBLEM

Parallel Plates

An identical pair of metal plates is mounted parallel on insulating stands 20 cm apart and equal amounts of opposite charges are placed on the plates. The electric field intensity at the midpoint between the plates is 400 N/C.

(a) What is the electric field intensity at a point 5.0 cm from the positive plate?

(b) If the same amount of charge was placed on plates that have twice the area and are 20 cm apart, what would be the electric field intensity at the point 5.0 cm from the positive plate?

(c) What would be the electric field intensity of the original plates if the distance of separation of the plates was doubled?

Conceptualize the Problem

- The *electric field* between isolated parallel plates is *uniform*.
- The *electric field* between isolated parallel plates depends on the *charge density* on the plates.

Identify the Goal

The magnitude of the electric field, $|E_Q|$, under three different conditions

Identify the Variables and Constants

Known	Unknown
$\lvert E_{Q(initial)}\rvert = 400$ N/C	$\lvert E_{Q(final)}\rvert$

Develop a Strategy

The magnitude of the electric field intensity is uniform between parallel plates, so it will be the same at every point.

$$|E_Q| = 400\ \frac{\text{N}}{\text{C}}$$

(a) The magnitude of the electric field intensity is 400 N/C at a point 5 cm from the positive plate.

The magnitude of the electric field intensity is inversely proportional to the area of the plates.

$$|E_{Q_1}| \propto \frac{q_1}{A_1} \quad \text{and} \quad |E_{Q_2}| \propto \frac{q_2}{A_2}$$

Divide.

$$\frac{|E_{Q_2}|}{|E_{Q_1}|} = \frac{\frac{q_2}{A_2}}{\frac{q_1}{A_1}}$$

Substitute.

$$q_2 = q_1 \quad \text{and} \quad A_2 = 2A_1$$

$$\frac{|E_{Q_2}|}{|E_{Q_1}|} = \frac{\frac{\cancel{q_1}}{2\cancel{A_1}}}{\frac{\cancel{q_1}}{\cancel{A_1}}}$$

$$|E_{Q_2}| = \frac{|E_{Q_1}|}{2}$$

$$|E_{Q_2}| = \frac{400\frac{\text{N}}{\text{C}}}{2}$$

$$|E_{Q_2}| = 200\ \frac{\text{N}}{\text{C}}$$

(b) The magnitude of the electric field intensity is 200 N/C when the area is doubled.

(c) The magnitude of the electric field intensity is 400 N/C (unchanged) when the distance is doubled, because electric field intensity is independent of the distance of separation.

Validate the Solution

Only the charge density affects the field intensity between the plates. Therefore, changing the area of the plates and consequently reducing the charge density is the only change that will affect the value of the field intensity.

PRACTICE PROBLEMS

1. A pair of metal plates, mounted 1.0 cm apart on insulators, is charged oppositely. A test charge of +2.0 μC placed at the midpoint, M, between the plates experiences a force of 6.0×10^{-4} N[W].

(a) What is the electric field intensity at M?

(b) What is the electric field intensity at a point 2.0 mm from the negative plate?

(c) What is the electric field intensity at a point 1.0 mm from the positive plate?

(d) What are two possible ways in which you could double the strength of the electric field?

2. The electric field intensity at the midpoint, M, between two oppositely charged (isolated) parallel plates, 12.0 mm apart, is 5.0×10^3 N/C[E].

(a) What is the electric field intensity at a point 3.0 mm from the negative plate?

(b) If the plate separation is changed to 6.0 mm and the area of the plates is changed, the electric field intensity is found to be 2.0×10^4 N/C[E]. What was the change made to the area of the plates?

continued ▶

continued from previous page

3. A test charge of $+5.0\ \mu C$ experiences a force of 2.0×10^3 N[S] when placed at the midpoint of two oppositely charged parallel plates. Assuming that the plates are electrically isolated and have a distance of separation of 8.0 mm, what will be the force experienced by a different charge of $-2.0\ \mu C$, located 2.0 mm from the negative plate?

Parallel Plates and Potential Difference

In Chapter 7, you learned that the potential difference between two points in an electric field is the work required to move a unit charge from one point to the other. What generalizations can you make about potential difference between two parallel plates?

Consider a test charge, q, placed against the negative plate of a pair of parallel plates. You can derive an expression for the potential difference between the plates by considering the work done on a test charge when moving it from the negative plate to the positive plate.

- Write the equation for the amount of work you would have to do to move the charge a displacement, Δd. To eliminate the $\cos\theta$, work only with the component of displacement that is parallel to the force and therefore to the electric field.

$$W = F\Delta d \cos\theta$$
$$W = F\Delta d \text{ (parallel to field)}$$

- Write the expression for the force on a charge in an electric field.

$$\vec{F} = q\vec{E}_Q$$

- Substitute the expression for force into the equation for work. (**Note:** The vector notation and absolute value symbol will be used with the electric field intensity to avoid confusion with electric potential energy.)

$$W = q|\vec{E}_Q|\Delta d$$

- Divide both sides of the equation by q.

$$\frac{W}{q} = |\vec{E}_Q|\Delta d$$

- The definition of electric potential difference is work per unit charge.

$$\Delta V = \frac{W}{q}$$
$$\Delta V = |\vec{E}_Q|\Delta d$$

- Another useful equation results when you divide both sides of the equation by displacement.

$$|\vec{E}_Q| = \frac{\Delta V}{\Delta d}$$

ELECTRIC FIELD AND POTENTIAL DIFFERENCE

The magnitude of the electric field intensity in the region between two points in a uniform electric field is the quotient of the electric potential difference between the points and the component of the displacement between the points that is parallel to the field.

$$|\vec{E}_Q| = \frac{\Delta V}{\Delta d}$$

Quantity	Symbol	SI unit
electric field intensity	$\vec{E}_Q$	$\frac{N}{C}$ (newtons per coulomb)
electric potential difference	ΔV	V (volts)
component of displacement between points, parallel to field	$\Delta \vec{d}$	m (metres)

Unit Analysis

$$\frac{V}{m} = \frac{J/C}{m} = \frac{N \cdot \cancel{m}}{C \cdot \cancel{m}} = \frac{N}{C}$$

Note: When doing a unit analysis, it is very useful to remember that a volt per metre is equivalent to a newton per coulomb.

Potential Gradient

In general, a gradient is similar to a rate. While a rate is a change in some quantity relative to a time interval, a **gradient** is a change in some quantity relative to a change in position, or displacement; therefore, the expression $\frac{\Delta V}{\Delta d}$ is known as the **potential gradient**.

As you move from one plate to the other, the electric potential difference changes linearly, since $\Delta V = |\vec{E}|\Delta d$ and $\vec{E}$ is constant. So, if the potential difference across the plates is 12 V, the potential difference at a point one third of the distance from the negative plate will be 4.0 V. The potential difference is higher close to the positive plate. In other words, the potential difference increases in a direction opposite to the direction of the electric field.

Physicists commonly refer to the "potential at a point" in an electric field. As you know, there are no absolute potentials, only potential differences. Therefore, the phrase "potential at a point" means the potential difference between that point and a reference point. In the case of parallel plates, the reference point is always the negatively charged plate.

SAMPLE PROBLEM

Field and Potential

Two parallel plates 5.0 cm apart are oppositely charged. The electric potential difference across the plates is 80.0 V.

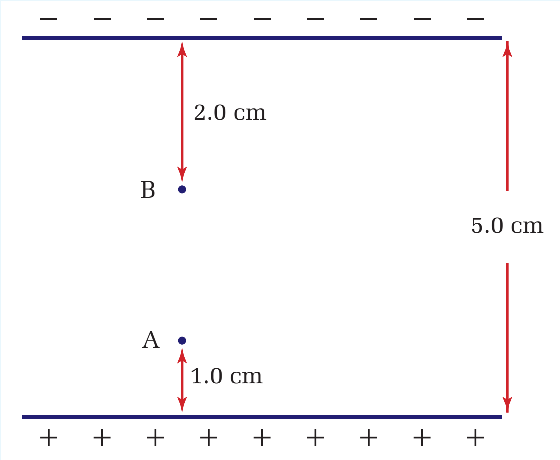
(a) What is the electric field intensity between the plates?

(b) What is the potential difference at point A?

(c) What is the potential difference at point B?

(d) What is the potential difference between points A and B?

(e) What force would be experienced by a small 2.0 μC charge placed at point A?



Conceptualize the Problem

- The *electric field* between *parallel plates* is *uniform*.
- Identify the lower plate as positive.
- The *electric field intensity* is related to the *potential difference* and the *distance of separation*.

Identify the Goal

The electric field intensity, $|\vec{E}_Q|$, between the plates

The potential difference at point A, V_A, and point B, V_B

The potential difference between points A and B, ΔV_{AB}

The electric force, $\vec{F}_Q$, on a charge placed at point A

Identify the Variables and Constants

Known	Unknown	
$\Delta d = 5.0$ cm	$\vec{E}_Q$	ΔV_{AB}
$\Delta V = 80.0$ V	V_A	$\vec{F}_Q$
Points A and B	V_B	
$q = 2.0\ \mu$C		

Develop a Strategy

The electric field is related to the potential difference and the distance of separation.

$$|\vec{E}_Q| = \frac{\Delta V}{\Delta d}$$

$$|\vec{E}_Q| = \frac{80.0\ \text{V}}{5.0 \times 10^{-2}\ \text{m}}$$

$$\vec{E}_Q = 1.6 \times 10^3\ \frac{\text{N}}{\text{C}}$$

directed from the positive to the negative plate

(a) The electric field intensity is 1.6×10^3 N/C away from the positive plate.

Use the equation that relates the electric potential difference to the electric field intensity. (**Note:** Point A is 4.0 cm from the negative plate.)

$$V_A = |\vec{E}_Q|\Delta d$$
$$V_A = \left(1.6 \times 10^3 \frac{\text{V}}{\cancel{\text{m}}}\right)(0.040\ \cancel{\text{m}})$$
$$V_A = 64\ \text{V}$$

(b) The potential difference at point A is 64 V.

Use the equation that relates the electric potential difference to the electric field intensity.

$$V_B = |\vec{E}_Q|\Delta d$$
$$V_B = \left(1.6 \times 10^3 \frac{\text{V}}{\cancel{\text{m}}}\right)(0.020\ \cancel{\text{m}})$$
$$V_B = 32\ \text{V}$$

(c) The potential difference at point B is 32 V.

Point A is at the higher potential, because it is closer to the positive plate.

$$\Delta V = V_A - V_B$$
$$\Delta V = 64\ \text{V} - 32\ \text{V}$$
$$\Delta V = 32\ \text{V}$$

(d) The potential difference between points A and B is 32 V.

The electric force is related to the field and charge.

$$\vec{F}_Q = q\vec{E}_Q$$
$$\vec{F}_Q = (2.0 \times 10^{-6}\ \cancel{\text{C}})\left(1.6 \times 10^3 \frac{\text{N}}{\cancel{\text{C}}}\right)$$
$$\vec{F}_Q = 3.2 \times 10^{-3}\ \text{N[away from positive plate]}$$

(e) The force experienced by the small charge at point A is 3.2×10^{-3} N, away from the positive plate.

Validate the Solution

The values are reasonable in terms of the given data. The units are logical.

PRACTICE PROBLEMS

4. Calculate the electric field intensity between two parallel plates, 4.2 cm apart, which have a potential difference across them of 60.0 V.

5. The potential difference between two points 8.0 mm apart in the field between two parallel plates is 24 V.

(a) What is the electric field intensity between the plates?

(b) The plates themselves are 2.0 cm apart. What is the electric potential difference between them?

6. When an 80.0 V battery is connected across a pair of parallel plates, the electric field intensity between the plates is 360.0 N/C.

(a) What is the distance of separation of the plates?

(b) What force will be experienced by a charge of –4.0 μC placed at the midpoint between the plates?

(c) Calculate the force experienced by the charge in part (b) if it is located one quarter of the way from the positive plate.

7. What electric potential difference must be applied across two parallel metal plates 8.0 cm apart so that the electric field intensity between them will be 3.2×10^2 N/C?

8. The potential gradient between two parallel plates 2.0 cm apart is 2.0×10^3 V/m.

(a) What is the potential difference between the plates?

(b) What is the electric field intensity between the plates?